Auscultation Based Stethoscopic Diagnostic Device for Cardiac Murmur Identification

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***Abstract*—In a healthy heart, there is no any abnormal blood flow takes place inside, in addition to the usual blood circulating pattern. However when the valves or tissues inside the heart are in diseased conditions, this usual blood flow pattern gets changed. As a result, abnormal sounds are produced with the normal heart beat sound. These abnormal sounds are known as cardiac murmurs. By identifying the murmur type doctors can diagnose the cardiac pathology related to that particular murmur type. This paper describes an electronic stethoscopic device that can be used as a stethoscope as well as murmur identification equipment. Chest piece of an ordinary stethoscope has been used to capture the heart beat with a microphone attached to it. Then the captured signal is amplified and sampled in the device itself and the sampled data is then transmitted to the central location to carry out the signal processing. Since there is a processor inside the device, processing of data can also be done in the device if required. Also the device has the capability of storing the sampled data for future analysis.**

***Keywords*—Auscultation, Cardiac Murmur, Signal Processing, Stethoscope, Diagnose**

I. Introduction

There are several methods available for disease diagnosis related to the cardiology. Auscultation is one of the simplest but a very useful method used to diagnose many cardiac pathological conditions. Also it is Cardiac auscultation is non-invasive, inexpensive and fast [1]. Cardiac pattern differs from the normal waveform whenever there are abnormalities occur in the tissues or valves of the heart. This will lead to produce abnormal sounds called as murmurs. The frequency of the murmur bears a direct relationship to the velocity of blood flow [2]. As an example some higher order frequency components will appear in the acoustic heart waveform in the disease known as coronary artery disease (CAD) [3].

In general, abnormalities listen by the auscultation of the heart is the main diagnosing method even before they are identified by ECG [4]. However even a large portion of the fresh medical graduates are unable to diagnose the cardiac abnormalities by auscultation according to the literature [5]. One reason is the decline of teaching of auscultation in medical schools [6] and the consequent lack of confidence and accuracy in identifying the heart sounds and murmurs in the clinical practice [7]. Because of that reason, there are some methods available which gives visual aids as well. For an example, electro cardio gram (ECG) is one of such methods that give visual aids to diagnose the problems related to the cardiac electrical activity. As the cardiac sounds are produced due to the turbulent blood flow and the mechanical activity of the heart, it is difficult to get an idea about the auscultative characteristics of the heart due to the non linear relationship between the timing of electrical and mechanical activities in a particular cardiac cycle. This is mainly due to the difference of the pathological conditions [8], [9]. Also there are methods to visualize the cardiac mechanical activity as well. Phonocardiogram (PCG) is such a method in which a graph is plotted for the cardiac acoustics. This method is popular in diagnosing cardio vascular diseases [4].

In a human heart there are four types of valves are present and they are named as Aortic valve, Pulmonic valve, Tricuspid Valve and the Mitral valve. Tricuspid valve is the valve that separates right ventricle and the right atrium. Mitral valve is the valve that separates the left ventricle and the left atrium. This is illustrated in Fig.1.

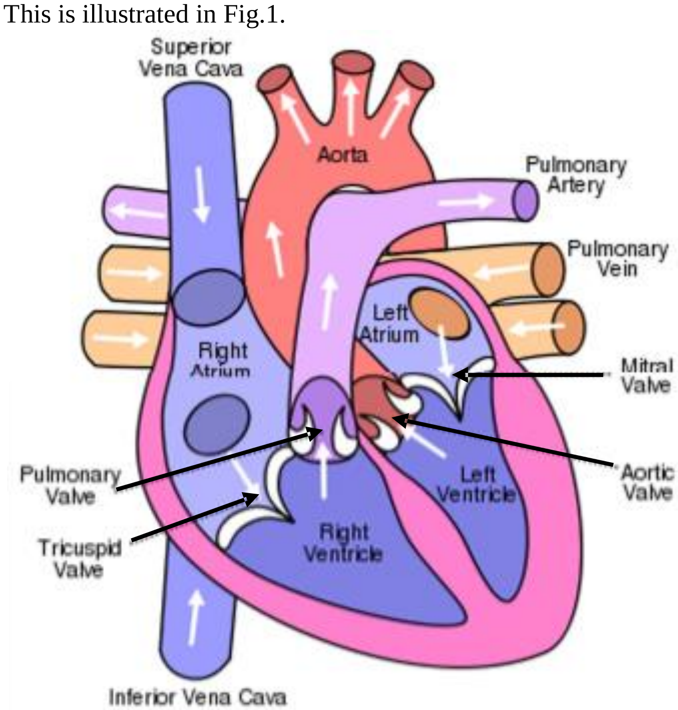

Fig. 1. Blood circulations and valves of the heart

Heart sounds are divided in to two beats as first beat (S1) and the second beat (S2). The time period between the S1 beat and the S2 beat are due to the contraction phase and is named as the systole. The time period between the S2 and S1 is due to the expansion of the heart and called as the diastole [11]. S1 beat occur when the mitral valve with the tricuspid valve is closed. S2 beat occur when the aortic valve with the pulmonic valve is closed [14].

There are two types of murmurs named as systolic murmurs and diastolic murmurs. This categorization has been done considering the occurrence of the murmur in the heart cycle. [10], [11]. Diastolic murmurs occur in the expansion phase of the heart cycle and the systolic murmurs occur in the contraction phase of the heart cycle [11]. There are combined murmurs also present in addition to the basic types of murmurs. Diagnosing the complex cases are much more difficult than to the individual murmur cases. In general, echo cardiogram test results are taken as an aid to identify those complex murmur situations. Heart murmurs are particularly common among children. However they may be present in individuals of any age. Prevalence of heart murmurs among children range from 72% to 80% [12] and from 29% to 60% among the elders [13].

This is an approach made to design and develop a bio medical acoustic device that can be used as an electronic stethoscope with an ability to identify the type of the murmur. The specialty of this device is the ability of doing the signal processing in the stethoscopic device itself unlike the electronic stethoscopes that are already available in the market. A processor built with ARM technology with a considerable digital signal processing power has been selected for the processor of the device. Architecture of the stethoscope is shown in Fig. 2.

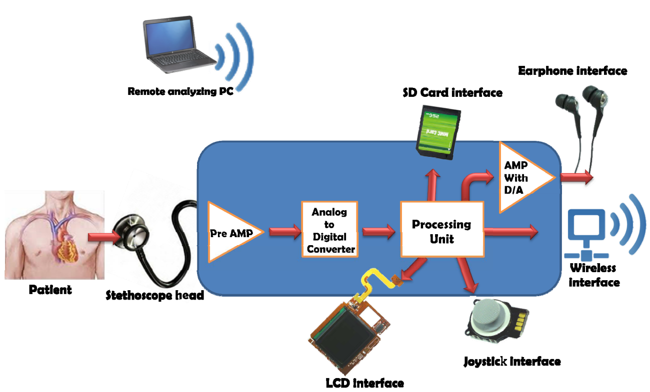

Fig. 2. System architecture of the stethoscope

II. SYSTEM MODELING

1. *Design of the Chest Piece*

There are various methods have been used in the previous approaches to capture the heart beat. To ensure a good capturing of the heart sound, chest piece of an ordinary stethoscope has been used as the patient's end of the device.

In general, the heart sounds are consists of higher order frequency components. Therefore an electret having a flat frequency capturing ability has been attached to the chest piece in order to obtain a digital signal from the patients end.

Microphone was connected very nearby to the chest piece so as to reduce the attenuation of the sound inside the rubber tube connecting the chest piece and the electret. Flexible rubber tube was selected to make the connection as it fits well to both the stem of the chest piece and the microphone. This is illustrated in Fig. 3.

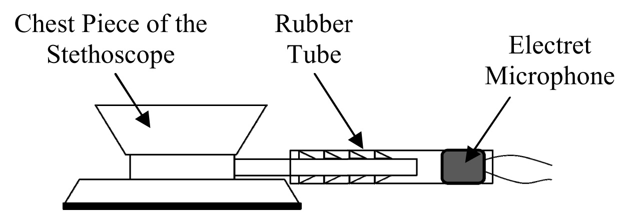

Fig. 3. Condenser microphone assembly to the chest piece of the stethoscope

Microphone and a female socket of a 3.5mm stereo audio jack were coupled together with a screen wire. Later the complete assembly was given a better look by covering all the connected devices with a black color heat shrink. This complete assembly of the chest piece of the stethoscope is shown in Fig 4.

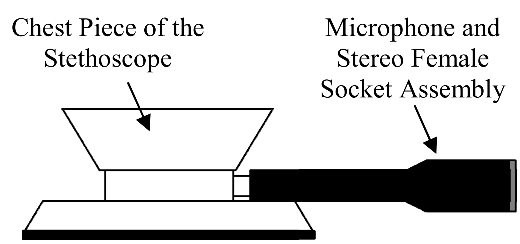

Fig. 4. Completed assembly of the chest piece

This chest piece assembly and the main functioning unit of the stethoscope contacting the processor is connected together using a screen wire cable to avoid the distortions caused by the outside interference problems. Two stereo mail jacks at both ends of the wire allow the easy detachment of the chest piece from the main controlling unit, increasing the flexibility of the product.

2. *Stethoscope unit enclosure*

This device is mainly designed to be used by the doctors who are not having good experiences with the electronic components. Therefore it was an essential fact to design an enclosure for the stethoscope to cover all the electronic circuitry parts while the necessary parts of this stethoscope are kept exposed to the outside.

This enclosure was designed in to two separable parts to make it easier to open when the necessity arise. Enclosure covers the micro processor board, Batteries, Amplifier, Filter and the Wireless Module and exposes only the Liquid Cristal Display (LCD) and the control buttons to the outside.

3. *Amplifier Module*

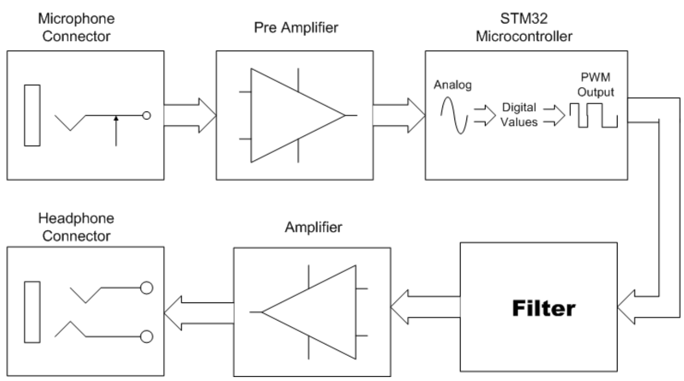

Fig. 5. Amplifier module

Amplifier for the stethoscopic device was built using multiple operational amplifier modules as the condenser microphones usually produces very weak electrical signals to the variation of the heart sound. Therefore it is essential to get a proper amplified signal so that the sampling can be done in the processor of the stethoscope. Fig. 5 illustrates the designed amplifier module for the stethoscope.

Capacitors are used here to do the filtering for the unwanted sounds captured by the chest piece. This filtering was done to ensure that the user of this stethoscope hears the heart sound as exactly as the sound heard from a traditional stethoscope except to the sound amplification.

4. *Processor and Wireless Module*

For this research, a high speed ARM processor of 72MHz has been used. The main reason for this selection is to carry out the signal processing part in the processor itself without a computer where necessary.

A radio frequency wireless module has been used to transmit data to the central location.

5. *User Interface Design*

One objective of this research is to design a very user friendly device. As a part of that, very friendly user interface has been designed to be operated at the central location. This interface has been designed using MATLAB and is shown in Fig. 6.

This interfacing software can maintain the data connection between the central location and the stethoscope if the stethoscopic device is in the range of the wireless module.

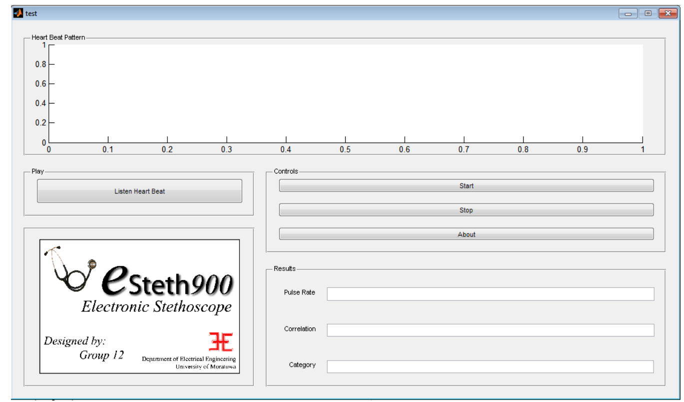

Fig. 6. User Interface at the central location

Also this can automatically get the data from the stethoscopic device soon after the data sampling is done.

This can display the patient ID, pulse rate, wave form of the heart beat and any identified abnormality of the heart if exists. Also this can playback the received data if required.

6. *Signal Processing*

This is the major part of the project. To obtain the outputs from the user interface, signal processing is carried out. Major outputs from the signal processing are,

1. Pulse rate
2. Heart sound correlation and pattern matching

6.1. *Obtaining the Pulse Rate*

In general, the waveform of the heart sound contains distinguishable peaks which may correspond to the beginnings of either systole or the diastole of the heart phase. To compute the pulse rate, number of samples between two major peaks which are in the same phase is obtained. Then the pulse rate can be calculated as follows (1).

$$Pulse\ Rate = \frac{F_S}{\text{No of Samples}} \times 60 \qquad (1)$$

where F_s is the sampling frequency of the processor.

6.2. *Heart Sound Correlation and Pattern Matching*

Fast Fourier Transform (FFT) and Correlation algorithms are used for the pattern matching. Receiving data from the stethoscopic device is first written to a data file. After getting the sampled data that is in the ASCII format from the stethoscope device, the data is first written to a text file. Then the raw ASCII data is carefully separated and the useful data is extracted

Then the extracted data is subjected to the FFT and obtain the magnitude of the each data. After that the received data is correlated with the existing waveform data which have also been undergone to FFT and taken the magnitude.

Cross correlation algorithm is used to identify the type of the cardiac murmur. The correlation algorithm that was used is listed in the following equations.

$$SSxx = \sum(x_i - \bar{x})^2$$
$$= \sum x^2 - 2\,\bar{x}\sum x + \sum \bar{x}^2$$
$$= \sum x^2 - 2\,n\bar{x}^2 + n\bar{x}^2 \quad (2)$$

Auto correlation function can be represented as in (3)

$$SSyy = \sum(y_i - \bar{y})^2$$
$$= \sum y^2 - 2\,\bar{y}\sum y + \sum \bar{y}^2$$
$$= \sum y^2 - 2\,n\bar{y}^2 + n\bar{y}^2$$
$$= \sum \bar{y}^2 - n\bar{y}^2 \quad (3)$$

Similarly,

$$SSxy = \sum(x_i - \bar{x})\,(y_i - \bar{y})$$
$$= \sum x_i y_i - \bar{x}y_i - x_i\,\bar{y} + \bar{x}\,\bar{y}$$
$$= \sum xy - n\bar{x}\bar{y} - n\bar{x}\bar{y} + n\bar{x}\,\bar{y}$$
$$= \sum xy - n\bar{x}\bar{y} \quad (4)$$

$$ss_{xx} = N\ var(X) \quad (5)$$
$$ss_{yy} = N\ var(y) \quad (6)$$
$$ss_{xy} = N\ var(X, Y) \quad (7)$$

Equation (8) gives the correlation coefficient.

$$r^2 = \frac{ss^2{}_{xy}}{ss_{xx}\ \ ss_{yy}} \quad (8)$$

Other symbols used here have their usual meanings.

Correlation coefficient is obtained from the FFT data. This coefficient is a value between 0 and 1. If the two signals are exactly matching, the correlation coefficient is 1. Correlation coefficient deviates from 1 as the signal that was received from the device get differs from the reference waveform.

Having obtained correlation coefficient of the particular heart sound with all the reference waveforms, the reference waveform having the maximum correlation coefficient is taken as the predicted waveform and thereby the relevant murmur.

III. METHODS OF OPERATION

1. As a Normal Stethoscope with Sound Amplification

This acoustic device can be used as a traditional stethoscope with the sound amplification capability. The amplifier and a noise filter built in to the device facilitates to this. As there is a gain controller in the amplifier of the device, output level of the sound can be controlled by the user as he wishes. Heart sound that comes out of the chest differs from one patient to the other. For an example, heart sound that comes out of the skin is very less in fat patients. In such situations, user can put more gain to amplify the sound such that it is audible enough to the user. This is very much helpful when the user inspects patients.

2. As a Diagnosing Device

As there is a processor having a significant speed of 72MHz inside the stethoscopic device, this equipment can perform the signal processing inside the device itself. In addition to that, sampled data can be processed in the central location after transmitting them.

The main objective of this device is to identify the type of the murmur. The captured heart sound from the chest piece assembly is sampled in the processor inside the device and then it is then transmitted to the PC via a radio frequency (RF) module. With the aid of the software developed, the type of the murmur can be identified.

IV. RESULTS AND DISCUSSION

Following figures are the waveforms plotted by the computer software of the stethoscopic device based on the cardiac auscultation data of the patients having different types of murmurs. The heart sounds are sampled at 8 kHz.

Fig. 7 shows the graph of a normal heart.

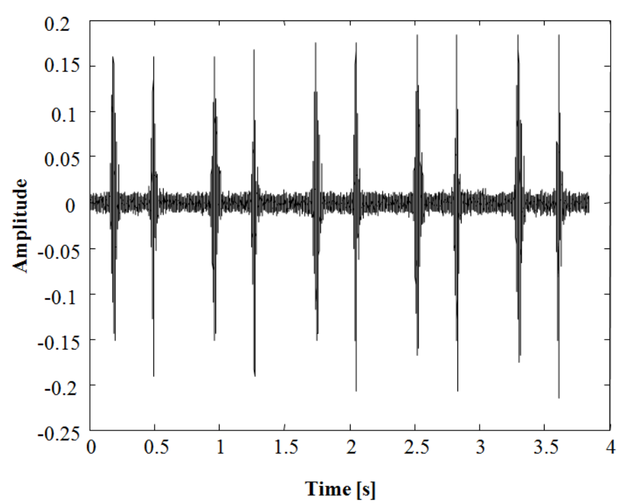

Fig. 7. Wave pattern of a normal heart sound

Heart sound of a normal heart is very clear and there are no any abnormal wave segments present in between the two major peaks of the heart waveform. The peaks correspond to the beginnings of the systole and the diastole. It is evident from the wave pattern that the intervals between two major peaks are different. The long interval corresponds to the diastole of the heart and the short interval corresponds to the systole of the heart. In the above figure, the left most peak is the S1 beat and the next peak is the S2 beat and it continues along.

Ejection murmur occurs due to the turbulent forward bold flow across the right ventricular and the left ventricular outflow tract, through the aorta or pulmonary artery, aortic or pulmonary valve. Fig. 8 is a wave pattern obtained for the ejection murmur. As it is observed, the intensity of the ejection murmur increases first and then decreases and hence gives a diamond shaped wave pattern. This is also referred to as crescendo-decrescendo pattern. Intensity of the murmur is proportional to the ventricular ejection rate. Intensity of the murmur will come to peak early if the flow is highest in the early ejection. In contrast, the peak of the murmur will come later if the flow is higher in the later phase of the ejection.

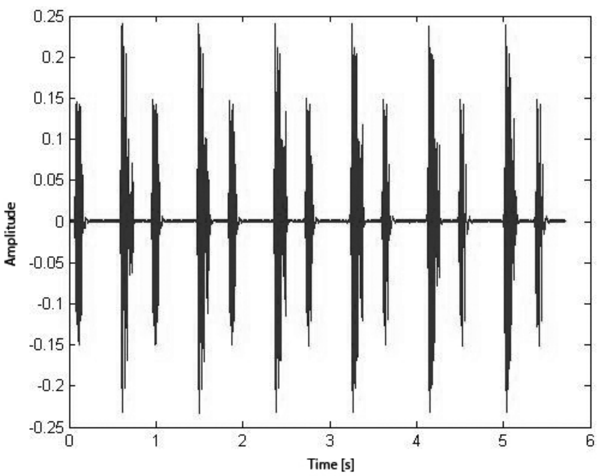

Fig. 8. Waveform of ejection murmur

Fig. 9 shows a waveform obtained from a cardiac auscultation data of a patient having Aortic regurgitation. This is also known as the aortic incompetence. This occurs due to the leakage of blood back through the aortic valve each time the left ventricle relaxes increasing the pressure and the volume of the blood in the left ventricle.

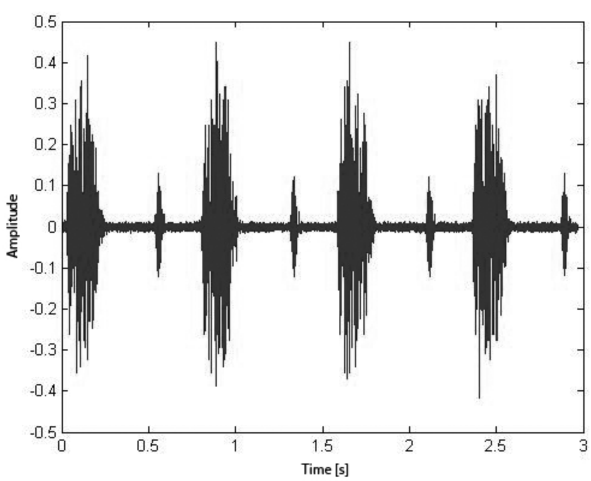

Fig. 9. Waveform of aortic regurgitation

As a result, the amount of work the heart has to do increases. Ventricle muscular walls will get thicken and the ventricle chambers will enlarged as a result. Even if the ventricle does this compensation, the heart may be unable to supply the blood requirement which will lead to a heart failure at the end. In general, aortic regurgitation causes no symptoms unless heart failure develops. Therefore the damaged heart valve must be replaced surgically as soon as possible.

Fig.10 illustrates a waveform obtained for the mitral valve stenosis. This occurs due to the narrowing of the mitral valve opening leading to increase resistance to blood flow from the left atrium to the left ventricle. As a result, the volume and pressure of blood in the left atrium increases while it enlarges and it will begin to beat rapidly in an irregular pattern.

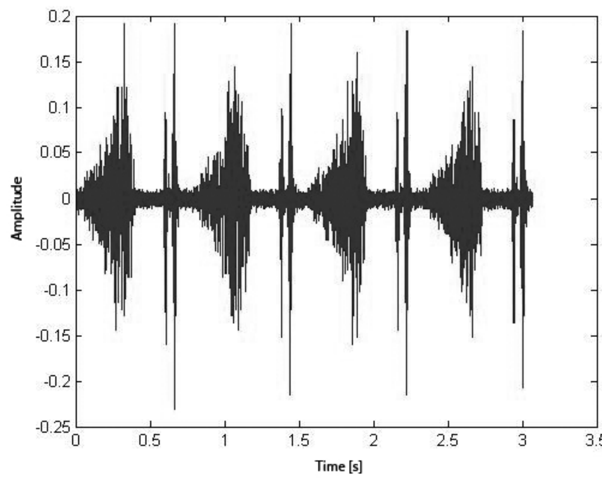

Fig. 10. Waveform of mitral valve stenosis

This will lower down the overall pumping efficiency of the heart. In the severe conditions of the mitral valve stenosis, oxygen level of the blood goes down and the pressure of the blood vessels inside the lungs increases and eventually resulted in a heart failure. As in aortic regurgitation, mitral stenosis does not usually cause symptoms until the situation becomes worse.

This device has been tested with the heart sounds of the patients who have been identified to have exactly one type of heart murmur. Results obtained from the test for normal heart sound and five different murmur conditions are illustrated in table I.

TABLE I
ACCURACY OF THE DEVICE FOR SEVERAL CARDIAC CONDITIONS

Type of Murmur	Percentage of Accuracy
No Disease (Normal Heart)	98
Early Systolic Murmur	83
Pulmonary Valve Stenosis	88
Aortic Regurgitation	78
Ejection Murmur	80
Mitral Valve Stenosis	85

It is seen from the test results that many of the accuracy levels of the corresponding murmurs are in the range 75% – 85%. It is expected to increase this accuracy level by using a better signal processing algorithm.

V. Conclusion and Remarks

This research was aimed to develop an acoustic device that can be used as traditional stethoscope with the sound amplification capability as well as a stethoscopic device with an ability to diagnose the type of the cardiac murmurs. Device has been tested for its accuracy for several types of murmurs and the corresponding waveform patterns have been obtained from the user interface at the central location. User can hear the noise filtered amplified heart sound through the earphone in real time and later as well. With the use of the gain controller, the user can control the gain accordingly to inspect patients regardless of the fat present on the chest.

As a diagnostic device, type of the murmur can be identified and the pulse rate can be calculated. These information can be displayed both on the user interface at the central location and on the LCD display of the device. Sampled data can be transmitted via the wireless medium to the central location for further analysis and also the data can be stored in the SD card in the stethoscopic device for later acquisition and playback.

Improvements can also be carried out for further to diagnose the complex situations where several murmurs present together. With the use of better signal processing algorithms, results of higher accuracy can be obtained.

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